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Research Article

THE STANDARD MILLING TIME OF FLAT SURFACES WITHOUT OUTLINE RESTRICTIONS

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ABSTRACT

Knowing the standard operating times of technological operations is essential element in the business operations of every production enterprise. It is the basis for establishing the production capacity, planning the production schedule, or even calculating costs. The article presents a variety of methods used in the calculation of standard worktime of technological operations. An especially important distinction was made between calculating the total machining time and the actual cutting time. Through the examination of various machined flat surfaces, the results of worktime calculations from CATIA and the authored mathematical model are presented.

Keywords: machining time, concentric milling, bidirectional milling, cutting time, additional time.

INTRODUCTION

Knowing the standard operating times of technological operations is essential element in the business operations of every production enterprise. It is the basis for establishing the production capacity, planning the production schedule, or even calculating costs. Currently the estimation of production costs is being done during the design stage. This method allows the selections of an effective production variant [1].

The standard milling time is determined by a few elements that can be defined analytically and through estimation. In the case of machining, analytical calculations are conducted in relation to the main machining time on machine tools. The main machining time is defined as the time required to change the shape, surface quality and the properties of the machined object. The mathematical equations used to calculate the main machining time are composed of the actual time the machining operation takes along with the tool approach and return time [2, 3]. The common method for calculating the main machining time depends on using the geometry of the machine part that comes from its CAD models. On the basis of the part's geometry the volume of material that is to be removed is calculated and the machining time is calculated after the machining parameters are taken into account. The process of calculating machining time is currently being automated, and as result so are the dependent machining costs [4, 5]. However, research shows that the results achieved through automatic methods are not always satisfactory [6]. In cases with simple geometry, the calculated results are approximately equal to the actual geometry [7]. In more complex cases, the difference is much more noticeable. In order to remedy this, the type of machining (accuracy and surface quality) and the dynamics of the machine tool are accounted for [8, 9]. Calculating costs is not limited to mathematical models. The literature presents a basis of elementarily developed method used to calculate the manufacturing costs of products of a similar geometry [10].

Another term that exists, machine time, is used often interchangeably with main machining time. The term cutting time is defined as the time the cutting edge is contact with the machined material [11]. When analyzing the contemporary machining process done on CNC machine tools, a clear difference between the cutting time and main machining time can be observed. As a result, using these two terms interchangeably can be seen as a mistake when considering the durability of the cutting tool. In addition to this, the calculation machining operations of irregular shaped outlines done using CAM software, that are later produced on CNC machine tools, can be problematic. This results from the complex tool path involved with machining such surfaces. In certain cases, it is possible to analytically calculate these times on the basis of the geometry of the machined part while accounting for the machining method. The following work is the beginning of a series of publications that aim to prepare a machining calculation method for parts that can be used during cost calculation stage of machining order. Furthermore, it can be used to calculate the cutting time that differs from the main machining time presented by CAM. These times are essential during the calculation of cutting tool requirements.

METHODS

Surface machining characteristics

The machining of surfaces is called planing. It is one the first stages of machining relating to flat surfaces. The main goal of planing is evening of surface by removing a set layer of material. In the case of CNC machining, planing is one of many processes conducted on the machined part. When using conventional machine tools during mass production, planing is done as a separate operation. The planing process is connected to the shaped of the machined surface. When done on conventional milling machines, the tool path is characterized by parallel tool passes that result from the linear translation along the machine's axis. On the other hand, CNC milling machines can, along parallel passes, machine the part in a concentric method that fits with its outline, or even rectangular sections of semi-finished product footprints. This type of machining is accessible through CAM and CNC systems in the form of machining cycles. The above mentioned planing variants can be observed in Figure 1.

In the cases of parallel tool paths, bidirectional and one-way surface milling can distinguished. In the case of one-way machining, the tool must be moved over the machined material between passes. This ensure that machine method remains either concurrent or counter-concurrent. When analyzing the presented tool paths applied to the same surface, it can be noted that the machining times of every cases will be different. In the case of irregular outlines the problem becomes even more complicated.

Mathematical model for calculating production time

The literature presents a series of dependences that are used in the calculation of machining time. It should be also noted that the calculations are done for process when the material is machined evenly in a repeatable manner. Examples of this include machining holes, threads, milling/turning a determined length etc. However, there are very differentiate surface shapes in practice. Additionally, when considering the determined requirements of dimensional accuracy or surface quality, the machining can be conducted using multiple process utilizing multiple machining parameters. This leads to various production times. When

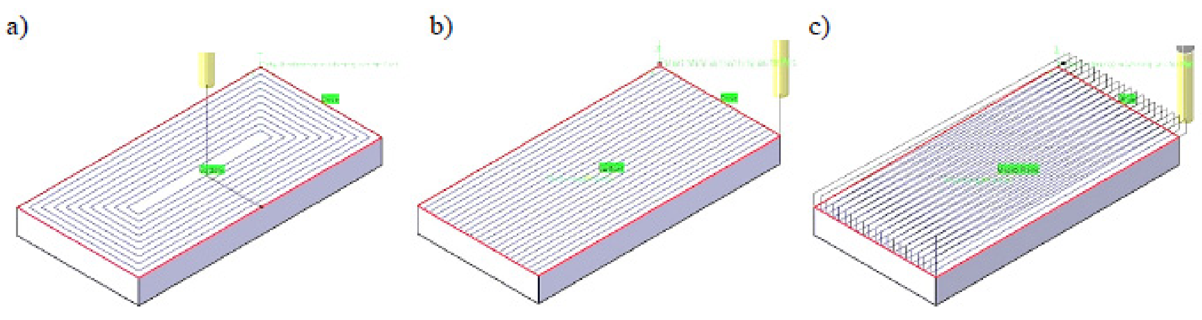

Fig. 1. Planing variants: a) concentric, b) bidirectional, c) one-way

considering any shape for the machined surface, it is assumed that the mathematical calculations will based on the value of this surface taken from the CAD environment. Machining time T_m is calculated in the following way:

$$T_m = T_s + T_p \quad (1)$$

where: T_s – cutting time [s],
T_p – additional time [s].

The cutting time is a results from the machined surface area based on the following equation:

$$T_s = \frac{60 \cdot S_p}{a_e \cdot V_f} \quad (2)$$

where: S_p – object surface area [mm^2],
a_e – cutting width [mm],
V_f – tool translation speed [mm/min].

Additional time includes the time without material removal s uch as the path for setting the tool. To calculate the additional time the following equation was used:

$$T_p = 60\left(\frac{L_p}{V_f} + \frac{S_r - S_p}{a_e \cdot V_f}\right) \quad (3)$$

where: S_r – tool movement area [mm^2],
L_p – tool setting path [mm].

RESULTS

Comparing and analyzing the execution times of various planning variants

During the comparison of execution times of machining flat surfaces of different outlines for various machining strategies resulting from CAD systems, it was assumed that every analyzed case would have a machined surface area of 10 000 mm^2. The milling tool would be the face of a cylindrical milling end with a diameter of 10mm and it will cut across its entire width. The accepted translation speed was set 500mm/min. The machining times were calculated using the results received from CATIA. Firstly, the machining times of a square surface with a side length of 100mm were calculated. The calculations were conducted for concentric and bidirectional machining strategies. Figure 2 demonstrates a visual representation of both cases.

The tool paths displayed in Figure 2 were generated in CATIA. It was assumed that tool would not go beyond the area of the object's machined surface. CAM systems present the execution time during machining simulations. The machining times generated by CATIA and the times calculated using the adopted mathematical method are presented in Table 1.

The CATIA calculated machining time of the square surface results in 130 seconds for the concentric strategy and 119 seconds for the bidirectional strategy. The longer machining time of the concentric strategy results from the additional tool movement between concentric passes. It is worth noting that the surface area in both cases is exactly the same. The analytically calculated execution times, based on the surface area and cut-

Table 1. Execution times for square surfaces

Concentric (s)	
CATIA	130
T_m	126
T_s	120
Bidirectional (s)	
CATIA	119
T_m	120
T_s	120

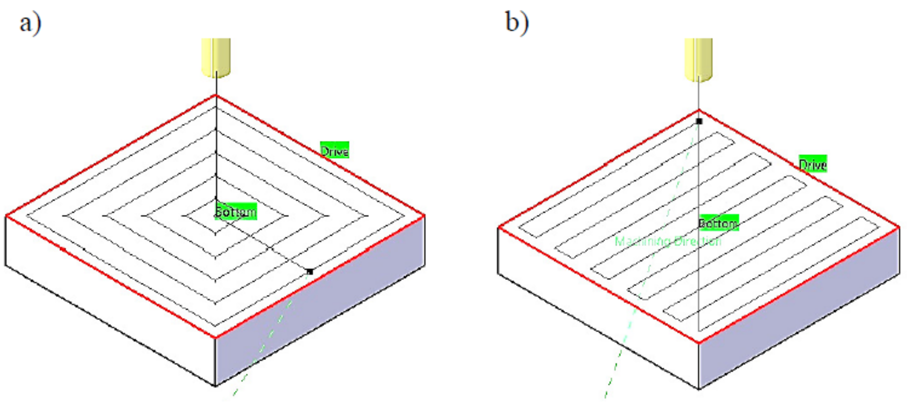

Fig. 2. Tool path used in machining square surfaces: a) concentric, b) bidirectional

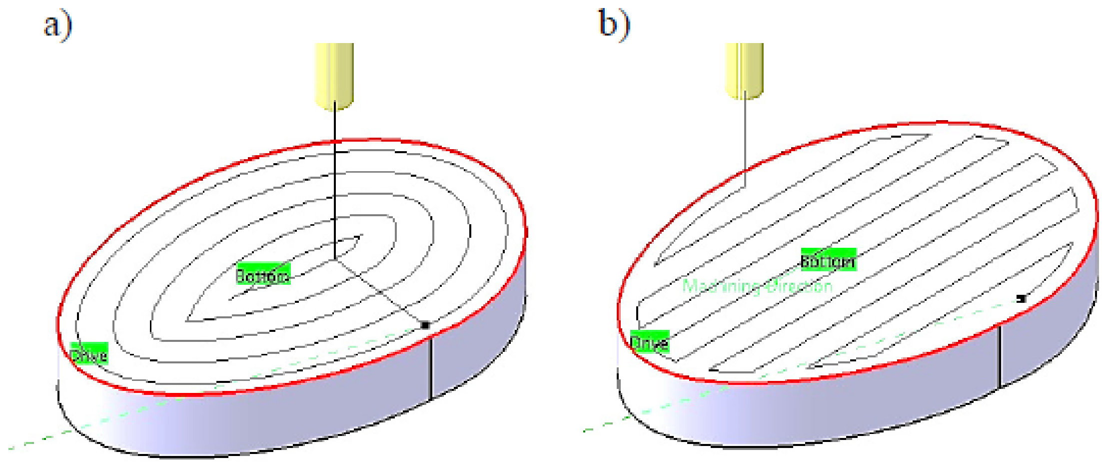

Fig. 3. Tool paths for surface machining of irregularly shaped surfaces: a) concentric, b) bidirectional

Table 2. Execution times for shaped surfaces

Concentric (s)	
CATIA	130
T_m	126
T_s	120
Bidirectional (s)	
CATIA	119
T_m	120
T_s	120

ting width, do not differ much. The bidirectional variant takes 120 seconds while the concentric method takes 126 seconds. It is worth noting that the cutting is 120 seconds in both cases.

A similar comparison was conducted for surface machining of planes with same surface area with irregular outlines. A view of the surface and the CATIA generated tool paths is presented in Figure 3. Calculated and CATIA simulation times are presented in Table 2.

The machining time calculated in CATIA for the concentric strategy is 130 seconds while the bidirectional strategies takes 116 seconds. The analytically calculated results based on surface area are identical to the case presented in Figure 2.

Irregular surface shapes are often machined in a rectangular area. The dimensions of the rectangle are based on the footprint of the machined surface. This type of machining is available in machining cycles in CNC machine tools and CAM systems. A view of the tool path for this case using the surface from the previous comparison is presented in Figure 4.

Assuming that the surface area is identical to the one in the previous case, the dimension of the rectangular area in this case are 1140×90 mm. The times for this case are presented in Table 3.

The machining time calculated in CATIA for the concentric strategy is 170 seconds while the bidirectional strategies takes 171 seconds. The analytical calculations based on surface area for the concentric strategy is 174 seconds

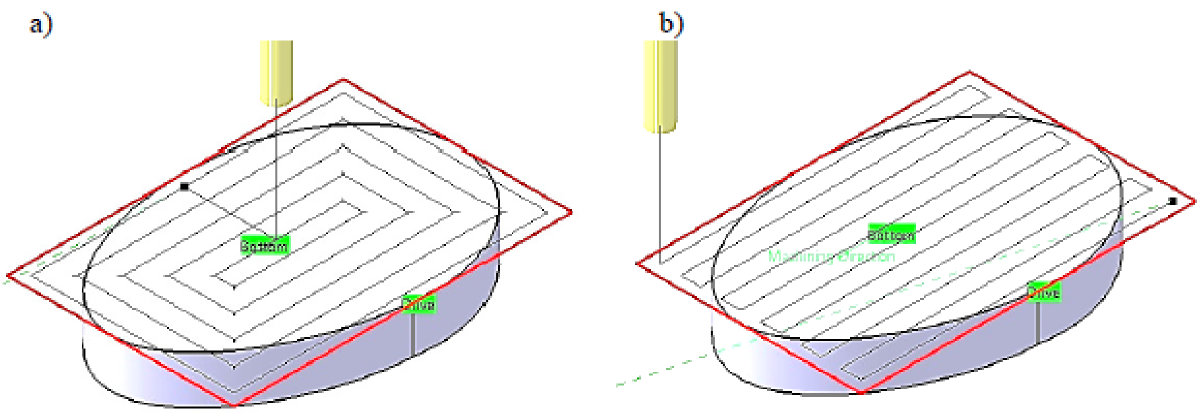

Fig. 4. Tool paths in a rectangular area of irregularly shaped surfaces: a) concentric, b) bidirectional

Table 3. Execution times of a surface within a rectangular area

Concentric (s)	
CATIA	170
T_m	174
T_s	120
Bidirectional (s)	
CATIA	171
T_m	168
T_s	120

while the bidirectional strategies takes 168 seconds. Obviously the cutting was 120 seconds for both strategies.

A common occurrence in the machining of surface is the presence of various recesses. These areas are often covered by a tool path, where the material is not removed. This cases is presented in Figure 5. by a surface area of 10000 mm^2 with a recess of 1000 mm^2. The resulting execution times from Figure 5 are presented in Table 4.

The machining time calculated in CAM for the concentric strategy is 145 seconds while the bidirectional strategies takes 130 seconds. The analytical calculations based on surface area for the concentric strategy is 138 seconds while the bidirectional strategies takes 132 seconds.

Table 4. Execution time of a surface with a recess

Concentric (s)	
CATIA	145
T_m	138
T_s	120
Bidirectional (s)	
CATIA	130
T_m	132
T_s	120

CONCLUSION

The calculation of execution times of determined machining processes, when analyzed from the perspective of CNC machine abilities, is a complex issue. Machining times are calculated by the CAM software, however this is tied with preparing the machining technology, which during the production order analysis stage and initial cost estimation is not profitable. In addition, machining parts is not always profitable when using CAM software.

In the previously mentioned cases, the use of mathematical models to calculate execution time and essentially costs is justified. It can be stated that the calculation of machining times using the analytical method based on surface area are similar to the ones given by the CAM system. It should however be noted that the cutting times in some cases are significantly lower than the machining times. This results from places where there is tool movement without material removal.

The calculations done by the CAM machining simulation do not account for such areas. This can have a significant effect on the tool durability calculation. On the basis of the time derived from the CAM system, the full durability of the tool may not be utilized. Thus, the difference between machining time and cutting time must be made when calculated production times.

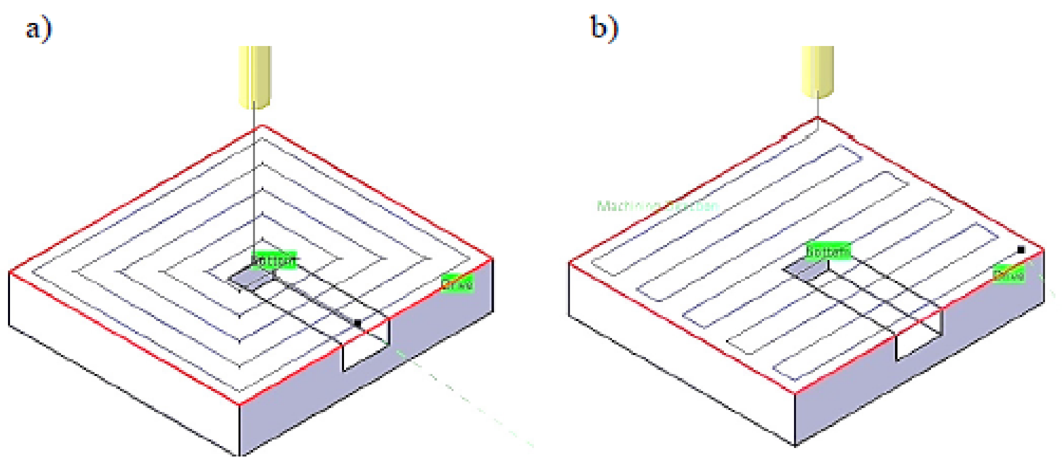

Fig. 5. Tool paths of surfaces with recesses: a) concentric, b) bidirectional

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